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This paper documents the history of photovoltaic use within the Department of Defense leading up to the installation of 2.1 MW of photovoltaics underway today. This history describes the evolution of the Department of Defense's Tri-Service Photovoltaic Review Committee and the committee's strategic plan to realize photovoltaic's full potential through outreach, conditioning of the federal procurement system, and specific project development. The Photovoltaic Review Committee estimate photovoltaic's potential at nearly 4,000 MW, of which about 700 MW are considered to be cost-effective at today's prices. The paper describes photovoltaic's potential within the Department of Defense the status and features of the 2.1 MW worth of photovoltaic systems under installation, and how these systems are selected and implemented. The paper also documents support provided to the Department of Defense by the Department of Energy dating back to the late 70s.

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Photovoltaics in the Department of Defense[1]

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Abstract. This paper documents the history of photovoltaic use within the Department of Defense leading up to the installation of 2.1 MW of photovoltaics underway today. This history describes the evolution of the Department of Defense's Tri-Service Photovoltaic Review Committee and the committee's strategic plan to realize photovoltaic's full potential through outreach, conditioning of the federal procurement system, and specific project development. The Photovoltaic Review Committee estimates photovoltaic's potential at nearly 4,000 MW, of which about 700 MW are considered to be cost-effective at today's prices. The paper describes photovoltaic's potential within the Department of Defense, the status and features of the 2.1-MW worth of photovoltaic systems under installation, and how these systems are selected and implemented. The paper also documents support provided to the Department of Defense by the Department of Energy dating back to the late 70s.

INTRODUCTION

The Department of Defense (DoD) is the largest single user of energy in the United States. It spends more than $2 billion annually for about 35,000 GWh of utility-supplied electricity (1). The Department also generates substantial amounts of energy to power remote facilities isolated from commercial utility grids. Best current estimates indicate that the DoD spends about $1 billion annually for about 3,000 GWh of electricity for off-grid facilities (2). The DoD recognized over 20 years ago that photovoltaics could reduce the cost of electricity and reduce dependence on fossil fuels for many off-grid facilities. However, a lack of awareness of, and experience with, the technology inhibited the use of photovoltaics for these cost-effective applications. The DoD has

[1]This work was sponsored by the Strategic Environmental and Development Program project EN-046 and by the U. S. Department of Energy under contract DE-AC04-94AL85000 in partnership with the Department of Defense Photovoltaic Review Committee.

implemented and maintained programs and policies to minimize these obstacles and foster the use of photovoltaics, efforts which began in the late 70s with the participation of all the military branches in the Department of Energy's Federal Photovoltaic Utilization Program (FPUP).

HISTORY OF PHOTOVOLTAICS IN THE DEPARTMENT OF DEFENSE

The Federal Photovoltaic Utilization Program was created to stimulate the use of photovoltaics in the federal sector and accelerate the growth of a commercially viable photovoltaic industry. Under FPUP, the DoD installed 218 systems at a cost of $5.8M (3). The photovoltaic arrays for these systems ranged from a single module up to 25 kW with the vast majority being less than 1 kW. Most were small dc systems for remote lighting, communications, instrumentation, battery charging, and range targets. There were several utility-tied systems as well as several stand-alone ac systems. The DoD's FPUP experience was the starting point of what has become a sustained and organized program within the DoD to use photovoltaics where appropriate. Working relationships formed during FPUP led to the creation of the DoD's Tri-Service Photovoltaic Review Committee in 1985.

The Photovoltaic Review Committee was chartered by the Office of the Secretary of Defense to encourage the use of photovoltaics as a standard technology where cost-effective and appropriate (4). The committee is chaired by Garyl Smith, of the Naval Air Weapons Station, China Lake, CA, and is composed of a representative from the Navy, Army, and Air Force. Current representatives are Chuck Combs, Naval Air Weapons Station, China Lake, CA, Roch Ducey, Army Construction Engineering Research Laboratory, Champaign, IL, and Larry Strother, Air Force Engineering and Services Center, Tyndall AFB, FL. Sandia National Laboratories has served as a technical consultant since the Photovoltaic Review Committee was chartered.

Focus on Small Remote Applications from 1985-1992

The Photovoltaic Review Committee's activities have evolved as the integration of the technology into military practices has progressed. Initial activities focused on identifying applications. In 1986, the Energy Program Office at China Lake surveyed approximately 300 installations and identified an estimated 21,000 potential cost-effective systems in 33 application categories (5). Table 1 summarizes these systems and applications. The arrays for these systems ranged from 7 W to 21 kW. In 1987, the Army surveyed seven installations and

identified cost-effective applications in 14 categories (6). The arrays for these applications, as shown in Table 2, ranged from 17 W to 9 kW. Overall, the Photovoltaic Review Committee estimated the potential for more than 50,000 small stand-alone systems with about 50 MW of photovoltaics (7). Having established the need for small remote photovoltaics systems, the Photovoltaic Review Committee shifted emphasis to outreach and education.

TABLE 1. Navy Survey on Potential Photovoltaic Applications

Application	No. of Systems	Typical Capital Costs ($)	Average Life-Cycle Costs ($)	Simple Payback (Years)
Building Guard Station	150	30,000	61,237	3.7
Building Operations (Remote)	20	248,000	60,636	9.9
Cathodic Protection	1,000	2,400	56,870	0.3
Communications (Island)	200	5,400	13,920	2.9
Comm. Repeater (Remote-Large)	300	25,600	70,080	2.9
Comm. Repeater (Large)	900	21,600	45,510	3.7
Comm. Repeater (Small)	900	10,800	48,144	2.0
Comm. Repeater (Remote-Small)	300	13,800	51,806	2.0
Communication Emergency	400	720	37,918	0.2
Communication Telephone	100	86,400	83,909	5.8
Lights, Small Craft	2,000	1,800	56,970	0.3
Lights, Target	100	14,400	66,643	1.9
Lights, Warning	1,500	1,440	116,766	0.1
Lights, Wind-Sock	200	7,200	2,176	<0.1
Meteorological Station (Large)	200	21,600	141,074	1.4
Meteorological Station (Small)	1,500	140	11,564	0.1
Aid to Navigation	300	1,440	57,300	0.2
Housing (Remote)	100	15,000	66,164	2.0
Instrumentation, Camera	400	45,000	141,039	2.4
Instrumentation, Offshore	20	45,000	133,311	2.7
Lights, Buoy	1,500	1,000	111,079	0.1
Lights, Heliport	100	28,800	2,439	<0.1
Lights Magazine	600	2,880	55,225	0.4
Observation Tower	200	72,000	100,344	4.6
Radar, Beacon (Small)	500	3,600	93,341	0.4
Radar, Beacon (Large)	300	14,400	68,974	1.9
Radar, Target	400	96,000	43,442	8.2
Remote Bomb Scoring	400	4,800	55,053	0.8
Security, Sensor	1,500	1,440	56,165	0.2
Security, Visual	600	14,400	69,974	1.7
Security, Gate	100	6,000	36,500	0.6
Transportable Power	3,000	48,000	138,600	2.6
Water Pumping	200	180,000	72,027	8.9

Personal networking and assessments of individual installations have been and will continue to be core Photovoltaic Review Committee functions. These functions are very effective in the development of photovoltaic advocates and in

the development of applications that lead to actual systems. Obviously, this approach cannot reach all installations nor all personnel involved in energy supply. To address a larger audience, the Photovoltaic Review Committee held a series of user-directed workshops in Albuquerque, NM (November 1989), Atlanta, GA (November 1990), and in Yuma, AZ (May 1991). The Department of Energy, through Sandia National Laboratories, supported this outreach effort with the SOLTECH 88 conference and with military-specific publications. SOLTECH 88 included sessions dedicated to photovoltaic usage in the military (8). Sandia edited and published two Photovoltaic Review Committee reports specific to the DoD: *Photovoltaics for Military Applications* (9) in 1988 and *Maintenance and Operation Manual for Photovoltaics* (10) in 1990. Sandia also provided technical presentations at the three user-directed workshops. The Photovoltaic Review Committee has also published a number of articles that document its activities and progress (11-15).

TABLE 2. Typical Load and Power Characteristics of Potential Photovoltaic Applications in the Army

Application	Approximate Array Size (W)
Test Range Equipment	25-150
Battery Chargers (for emergency power of water wells)	17-20
Clearance Lights (on water tanks)	770-2500
Global Positioning System Satellite Simulators	2000-2500
Mobile Firing Range	80-90
Mobile Generators	500-9000
Radio Repeaters	1400-1600
Firing Range Gun Position	100-110
Range Surveillance Video	1000-3500
Microwave Towers	1500-1700
Remote Data Acquisition	300-500
Meteorological Towers	200-220
Storage Facilities (Igloos)	300-320
Microwave Repeaters	1200-1600

The identification of applications and the education efforts of the Photovoltaic Review Committee promoted the installation of about 2,000 systems with about 2 MW of photovoltaics by 1992 (7). At this point, the Photovoltaic Review Committee considered the small remote system as approaching a mature application and shifted emphasis to the development and implementation of larger applications. Two major sources of funding, the Energy Conservation Investment Program (ECIP) and the Strategic Environmental Research and Development Program (SERDP), allowed the Photovoltaic Review Committee to greatly accelerate this new emphasis.

Shift to Larger Systems Beginning in 1992

The development and implementation of larger applications presented two major obstacles. One obstacle was the lack of suitable power processing hardware. The other was a ten-fold increase in the cost of larger systems compared with the small remote systems. The increased cost of larger systems includes both the engineering effort to develop larger applications and the cost of the systems themselves. SERDP provided funding to develop and test the required power processing hardware, and to develop the larger applications, while ECIP provided the funding for the larger systems.

It is important to understand the synergism of these two programs. ECIP is a military construction program. As a military construction program, ECIP funds can only be used for the design and construction of complete projects. They cannot be used for feasibility or engineering studies to develop projects and they cannot be used to develop or test new hardware. SERDP is a research and development program. As a research and development program, SERDP funds are intended to develop, test, and demonstrate new technologies. The DoD follows a standard progression to implement new technologies and applications. Figures 1a and 1b illustrate how SERDP and ECIP complemented each other to advance these larger photovoltaic systems toward implementation within this standard technology progression.

The first new application area addressed by the Photovoltaic Review Committee beyond small stand-alone was photovoltaic/diesel generator hybrids for remote facilities. (See the "Potential of Photovoltaics within the DoD" section for a description of application areas.) This intermediate remote application area required the development of 150-kW, three-phase power processing units with controls to integrate photovoltaics, batteries, and the diesel generator. Figure 1a shows that, prior to SERDP, this application area resided in what is referred to as the advanced development stage. This means that the required application functions had been developed (applied research) and that the switching and controls technologies required to perform those functions were available (basic research), but a functioning unit had not yet been fabricated and tested (advanced development).

There were no funds directed to this needed development and, as a result, the application area remained stagnant even though the Photovoltaic Review Committee had already identified 273 MW of cost-effective applications (16). SERDP provided $4M for the DoD photovoltaics program in FY92. Sandia used a portion of these funds to develop and test prototypes of this type of power processing hardware which, as shown in Figure 1b, advanced the intermediate remote application area from the advanced development area into the engineering development area, where the technology is evaluated in actual working systems. Several of these types of systems were then implemented under ECIP to verify

their performance and economics. The combination of ECIP and SERDP enabled the intermediate application area far sooner than originally expected. In 1990, the Photovoltaic Review Committee estimated that this area would not be ready for implementation until FY98. Because of ECIP and SERDP, the intermediate application area was ready for implementation by FY95.

The photovoltaic SERDP project was awarded a total of $12.8M from FY92 through FY95. The FY93 through FY95 cycles addressed the power processing needs for the next DoD applications areas: large remote and isolated grid. (See the "Potential of Photovoltaics within the DoD" section for a description of application areas.) Of the $12.8M, $4.3M was invested in engineering and development and $8.5M was invested in systems to demonstrate the large remote and isolated grid technologies. Figures 1a and 1b show the status of the power processing technology for these applications areas before and after the photovoltaic SERDP project. The technology was advanced in increments, building on the advances from the prior application areas. The advance for the large remote area added the ability to parallel units to achieve power capacities beyond the intermediate remote applications. This technology will be demonstrated in the Superior Valley system. (See the section "Status of ECIP and SERDP Systems.") The advance for the isolated grid area added the ability to parallel with external sources (such as a generator or the utility). This technology will be demonstrated in the Yuma grid support system. These advances were evolutionary rather than revolutionary, in that existing technology was integrated to produce power processing hardware compatible with the DoD's needs and requirements.

The net result of this effort was an integrated system of building-block units that could serve a facility independent of any other source (stand-alone inverter mode), assist an external source to serve a facility (parallel inverter mode), and charge batteries from an external source (rectifier mode). The advances were to include gradual and seamless transfers between all modes. This was completed for transfers between the stand-alone inverter and rectifier modes but not for the transfers to and from the parallel inverter mode because of reduced funding and early termination. Details of these technology advances are documented elsewhere (16).

As stated earlier, SERDP and ECIP greatly accelerated the use of photovoltaics within the DoD. The Photovoltaic Review Committee estimates that SERDP and ECIP have reduced the time to implementation of the large remote application area by seven years (see Figure 2). A similar acceleration may have been achieved for the isolated grid application area even though the full development effort for this area was not completed under SERDP.

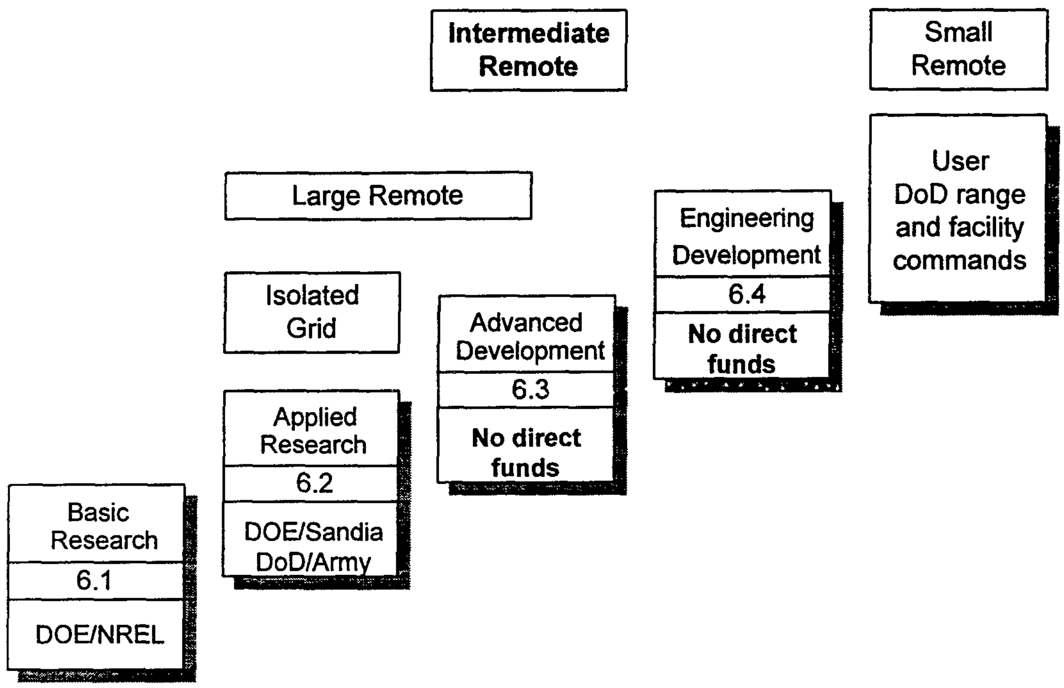

FIGURE 1a. Technology Status of Application Areas Before SERDP and ECIP.

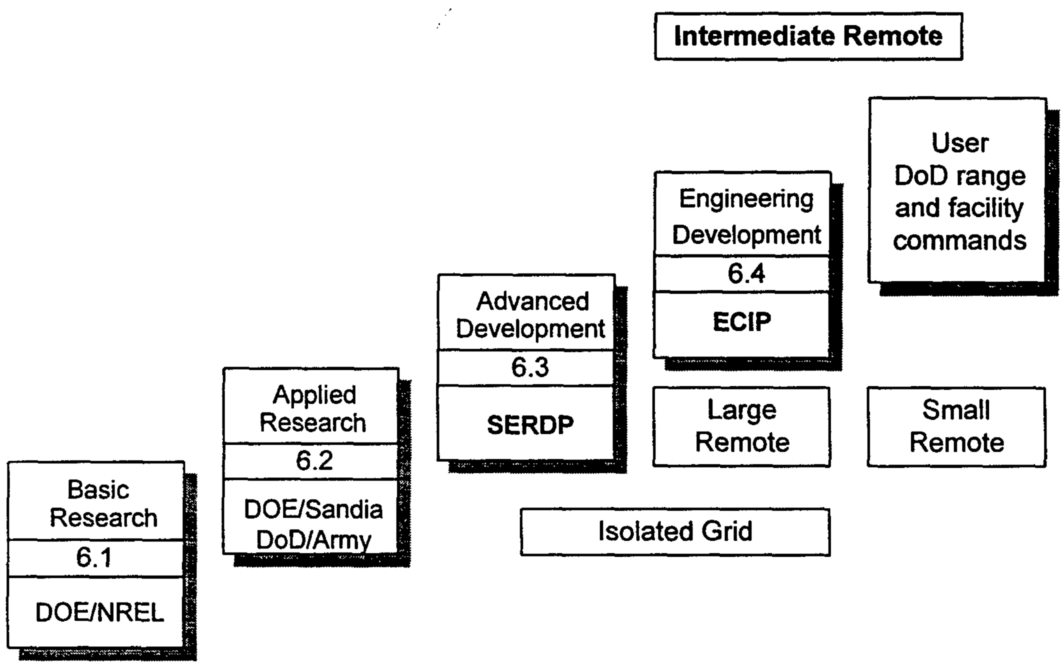

FIGURE 1b. Technology Status of Application Areas After SERDP and ECIP.

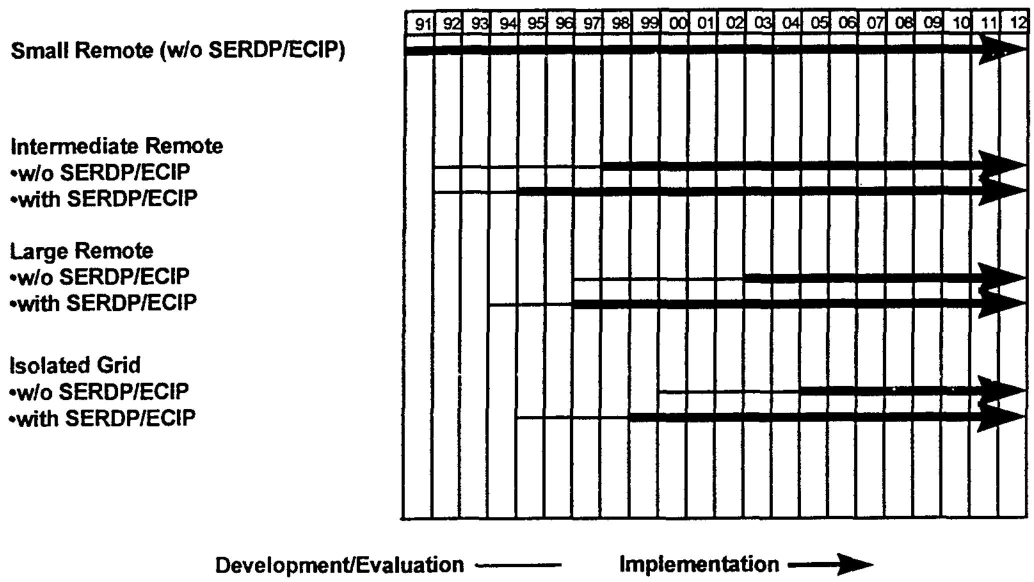

FIGURE 2. Effect of SERDP and ECIP on Implementation of Application Areas.

SERDP funds were also used for the creation of a living data base for DoD photovoltaic projects (17) and for the GloTech environmental assessment software (18). The data base was created to catalog potential photovoltaic projects and track photovoltaic systems. When fully developed, the data base will include a prioritized listing of approved projects. These projects can then be implemented as funding becomes available. The GloTech software, developed under the direction of the Environmental Protection Agency, quantifies environmental releases for both photovoltaic and conventional energy technologies. This is a cradle-to-grave analysis beginning with all materials and natural resources and ending with decommissioning and salvage. The software provides a means to compare the environmental consequences of one technology versus another.

Current Activities of the Photovoltaic Review Committee

In 1993, the Photovoltaic Review Committee published its strategic plan for photovoltaics (4). This plan documents the objectives of the DoD photovoltaic program and the strategies for realizing these objectives. The plan describes three core activities for the Photovoltaic Review Committee: (1) Outreach, (2) Logistic System Conditioning, and (3) Project Development. The level of activity, and consequently the rate of progress toward achieving the objectives defined in the strategic plan, fluctuates with the resources provided. Prior to ECIP and SERDP,

the Photovoltaic Review Committee depended on personnel resources provided by the three service branches with Department of Energy support through Sandia National Laboratories. The development and project funding from SERDP and ECIP accelerated the DoD photovoltaic program. However, funding cuts initiated by the 1994 Congress have again slowed the Photovoltaic Review Committee's progress. The photovoltaic SERDP project was dramatically cut in FY95 and then terminated in FY96 (the entire energy thrust area of SERDP was zeroed in FY97). ECIP funding of photovoltaic projects dropped from $5M in FY95 to $2.6M in FY96, and then to zero in FY97. The Photovoltaic Review Committee is pursuing financing mechanisms to offset these reductions in project funding (see the logistic system conditioning activity below). The Photovoltaic Review Committee's progress may fluctuate over time, but its direction and activities continue on the path defined in the strategic plan. These activities are described below.

Outreach, as described earlier, is designed to increase awareness of photovoltaic technology through networking, user workshops, and presentations and publications. The most recent outreach effort was the Renewable Energy Workshop at China Lake, CA (November 1995). Logistic System Conditioning is designed to integrate photovoltaics into the established federal procurement system to make the purchase of a photovoltaic system as routine as a conventional power source. The Federal Photovoltaic Utilization Program began this effort by encouraging federal agencies to integrate life-cycle costing into the economic evaluation process. Other efforts in this area include making photovoltaic modules and system components available through General Services Administration contracts and making photovoltaic systems available through streamlined procurement mechanisms like energy savings performance contracting (19) and utility off-grid tariff programs (20). Two of the Photovoltaic Review Committee's ECIP systems (Grasmere Point and Santa Cruz Island) were procured under utility off-grid tariff programs. Systems can also be partially or completely financed under these two mechanisms. Financing may become the primary mechanism to implement systems if the current environment of limited up-front funding continues.

The project development activity is designed to turn potential applications into actual systems. The activity focuses on helping installations identify potential applications, develop technical requirements, and satisfy institutional requirements. This activity has dominated the Photovoltaic Review Committee's activities since its emphasis shifted to implementation of larger systems in 1992. Nearly all the Photovoltaic Review Committee's personnel resources were required to identify and implement $28M worth of photovoltaic systems. At the same time, there has been a series of executive and congressional acts that mandate project development. The following paragraph summarizes these executive and congressional acts.

The DoD, like all federal agencies, is under continually increasing pressure to reduce energy consumption and control energy costs wherever possible. Executive Orders 12003 (1977), 12759 (1990) and 12902 (1994) set goals for increase in industrial energy efficiency for federal facilities. Order 12003 called for a 20% efficiency increase by 1985 (compared with 1975), Order 12759 called for an additional 20% by 2000 (compared with 1985), and Order 12902 extended this goal to 20% by 2005 (compared with 1990). (The goal from Order 12759 was reiterated in the Energy Policy Act passed by Congress in 1992.) In addition, the 1990 House Defense Authorization Act set a goal for DoD to implement 100 MW of renewables by 1996.

This treatise on the DoD's history with photovoltaics describes the evolution of the Photovoltaic Review Committee and the DoD photovoltaic program leading to the current emphasis on project development and implementation. The remainder of this paper focuses on the overall potential of photovoltaics within the DoD, the process used to select projects for implementation, and the status of 2.1 MW of systems resulting from ECIP and SERDP.

POTENTIAL OF PHOTOVOLTAICS WITHIN THE DoD

Table 3 gives the Photovoltaic Review Committee estimates of the overall potential for photovoltaics within the DoD (2). The photovoltaic potential is listed according to application areas in order of cost-effectiveness (small remote is the most cost-effective and bulk power/peak shedding is the least cost-effective). The small remote application area includes stand-alone systems dedicated to a single load, such as lighting and communications. The intermediate and large remote area is primarily augmenting diesel generators (hybrid systems) for remote training, testing, and evaluation facilities. The isolated grid area is primarily augmenting diesel generator based power plants (again hybrid systems) that serve an entire installation (a micro-utility grid). Most of the small stand-alone systems and about one-half of the hybrid systems are cost effective today based on life-cycle cost comparisons including operation and maintenance savings and enhanced reliability. The remaining areas are utility interactive applications.

Grid support is strategically placed photovoltaic power stations that support weak utility feeders. Distributed load centers are large utility-tied uninterruptible power systems for ultra-high reliability at critical facilities. Bulk power/peak shedding is central photovoltaic power stations to displace bulk power and control peak demand from the utility. Most of these applications are not cost-effective today.

All except 4 of the 124 ECIP and SERDP systems are remote applications (small remote and intermediate/large hybrids). The predominance of the remote systems is the result of the ECIP regulation that photovoltaics must be the least-

cost power source for the application. This trend will continue until costs drop significantly below the current $10 per watt of ac power for large utility-interactive systems (as was paid for the Yuma grid-tied photovoltaic power plant).

TABLE 3. Potential for Photovoltaics within the DoD

Application Area	Power Capacity (kW)	No. of Systems	Photovoltaics Required (MW)
Small Remote	<25	51,625	51
Intermediate/Large Remote	25-1000	3,875	423
Isolated Grid	>500	870	1,305
Grid Support	>500	200	600
Distributed Load Center	>500	800	250
Bulk Power/Peak Shedding	>500	1,200	1,200
TOTALS	---	*58,570*	*3,829*

STATUS OF ECIP AND SERDP SYSTEMS

Selection and Implementation Process

All Photovoltaic Review Committee members are tasked to identify and develop projects for their service branch. Projects are identified via surveys by the Photovoltaic Review Committee members and via requests for assistance from installations. The Photovoltaic Review Committee member first performs a preliminary assessment to establish that the project is technically viable and cost-effective. Subsequent activity depends on a set of factors including user support (support at the installation level and up through the chain of command), scope and cost, maturity of the technology, replicability within the DoD, and payback period. For small projects (in both scope and cost) with mature technology (small stand-alone systems), the Photovoltaic Review Committee provides information on how to develop system specifications and procure the system so the installation can pursue the project on its own. In general, the Photovoltaic Review Committee limits active involvement to projects that the installation cannot handle on its own.

In these cases, the Photovoltaic Review Committee, with support from Sandia when necessary, assists the installation to develop the system justification as required to obtain approval through the chain of command. This justification normally requires an economic comparison of the power alternatives, which in turn requires the development of a conceptual system and an estimate of the system performance. After the project is approved, it can be submitted to the appropriate funding or financing program.

Up to now, the primary funding program has been ECIP. Each fiscal year, the Photovoltaic Review Committee ranks the approved projects and submits the top projects for ECIP funding. The ranking is based on an evaluation of payback period, replicability, and user support. The number of projects submitted is limited by the available funding. The other project funding program was SERDP. These projects were selected to demonstrate specific technology advances.

After a project is selected and funded, it is assigned to the appropriate procurement agency and a technical working group is created to support the project through installation and start-up. The working group includes installation and Photovoltaic Review Committee personnel, with technical support from Sandia when necessary, and is tasked to develop system specifications, to help the procurement agency develop the solicitation package, to evaluate the technical content of proposals, to review and approve system design, and to define system acceptance and start-up criteria. The time required from developing the specifications to completion of construction varies widely depending on the complexity of the system and accessibility to the site. A reasonable time frame for a single system is about 6 months for contract award followed by 12 months to design and build it.

System Status

Since 1992, the DoD has invested \$28M for 124 photovoltaic systems through ECIP and SERDP. These systems represent a total of 2.1 MW of photovoltaics. \$19.5M was provided by ECIP with the \$8.5M balance from SERDP. Table 4 lists the main features and status of these projects. The majority of these are small stand-alone systems including 56 pop-up targets for the Pohakuloa Training Area (PTA ranges), 40 water pumps (Ft. Carson and Santa Cruz Island), and 12 range control towers (PTA ranges). Three are grid-interactive systems (Yuma grid-tied, Ascension Island, and PTA Bradshaw airfield). The Yuma grid-tied system is the most technically advanced and is representative of both the distributed load center and peak shedding applications areas. One is a regenerative fuel cell application (Edwards Air Force Base fuel cell). The remaining 12 are photovoltaic/diesel hybrid systems. A brief description of each system follows Table 4.

TABLE 4. Features and Status of ECIP and SERDP Systems

Project	Array (kWp)	Battery (KWh)	PPU[a] (kW)	Status
Superior Valley, China Lake, CA, Navy	344	3500	300	operational
Grasmere, Mt Home AFB, ID, Air Force	78	700	90	operational
San Clemente Island, Navy	94	2500	175	construction
Range 500, 29 Palms, CA, Marines	69	2000	180	design
China Lake Hybrids, CA, Navy				
• Junction Ranch	130	2000	250	construction
• Nato Site	134	2000	250	construction
• Kim Site	235	2000	250	construction
Pumps (39), Ft. Carson, CO, Army	<1	---	---	operational
PTA ranges, Hawaii, Army				
• Pop-up target (56)	0.01	1	---	development
• Control Towers (12)	0.4	6	---	development
• Track targets (2)	5	600	30	development
• Bradshaw airfield	2	600	5	development
Yuma grid-tied, Yuma, AZ, Army	441	5600	900	construction
Smart Munitions, Yuma, AZ, Army	225	3500	225	development
Mobile Power Center, Marines	3.4	58	6	testing
Ascension Island, Air Force	86	---	120	construction
Fuel Cell, Edwards AFB, CA, Air Force	50	---	---	operational
Santa Cruz Island, Navy				
• Communications site	138	2700	150	design
• Water Pump	11	---	---	design

[a] - Capacity of power processing unit (PPU)

Superior Valley, China Lake, California

This photovoltaic/diesel hybrid system powers the Naval Air Warfare Center's bombing complex at Superior Valley on the south range of China Lake. The prime contractor, Photocomm, Inc. was awarded $3.6M to design and install the system. The system includes 344 kW of ASE 300DG modules, a 300-kW Abacus power processing unit, and 3.5 MWh of C&D C170-19 batteries. This project is a SERDP-funded research and development project designed to advance power processing technology to allow "ganging" of multiple power processing units to achieve the power capacity required for larger DoD applications (see reference 21 for a detailed description of this system). The system also provides increased power capacity required by the expanding mission of the facility. The system was accepted by the Navy in September 1996.

Grasmere Range, Mountain Home Air Force Base, Idaho

This project provides power to electronic equipment located on Grasmere Range, approximately 80 miles from Mountain Home Air Force Base and 40

miles from the nearest utility grid. Previously, power had been furnished by diesel engines. The expanding mission of the Grasmere facility now requires year-round power with 24-hour power during the winter. Because of the severe winter weather at the site, 24-hour power with diesels alone is impractical. This project allows the Air Force to reduce the diesel engine run time thereby providing year-round power at a reasonable cost. The prime contractor, Idaho Power, was awarded $1.3M to design and install the system. The system was procured through Idaho Power's off-grid tariff program and includes 78 kW of Solarex MSX-120 modules, a 90-kW Advanced Energy Systems power conditioning unit, and 700 kW of Hoppecke batteries (see reference 21 for a detailed description of this system). Idaho Power is also under contract to the Air Force to maintain and operate this system. The system became fully operational in February 1996.

Range Electronic Warfare Simulator, San Clemente Island, California

Most of the facilities on San Clemente Island are served by a group of diesel generators that produce power for the island grid. However, the Range Electronic Warfare Simulator facility is isolated even from the island grid and depends on a series of generators to provide power to the equipment and housekeeping loads at the facility. The proposed system addresses the excessive costs associated with providing 24-hour power with diesel generators. The system will provide autonomous operation during weekends, which will substantially reduce operation costs. The system includes 94 kW of ASE 300DG modules, a 175-kW Kenetech power processing unit, and 2.5 MWh of GNB 85RC33 Resource Commander batteries. The procurement office is the Naval Facilities Engineering Command Southwest Division (SWDIV) in San Diego, and the Navy user is the Southern California Off-shore Range with headquarters at North Island in San Diego. Construction is 80% complete. The system is expected to be fully operational in January 1997. The prime contractor for this system is Integrated Power Corporation.

Range 500, Twenty-nine Palms, California

Range 500 is a remotely located tank target practice range isolated from the grid. Presently, diesel generators power a mechanism that drives tank pop-up targets along a track. Photovoltaics will supplement those generators and provide improved power quality and reliability. The prime contractor is Utility Power Group. The system will include 69 kW of Seimens J4F modules, a 180-kW Kenetech power processing unit, and 2 MWh of C&D C125-33 batteries. The

procuring agency is the Naval Facilities Engineering Command at San Diego (SWDIV). The project is in the final design stage.

Three Hybrid Projects at China Lake, California

A contract for $6.3 million was recently awarded to Plateau Electric for the design and installation of three separate photovoltaic hybrid systems at China Lake, California. These systems are for existing, remotely located test sites and are currently under construction. They are:

Junction Ranch - 130 kW of photovoltaics
NATO Site - 134 kW of photovoltaics
Kim Site - 235 kW of photovoltaics

These systems are standardized as much as possible. Each system has an identical 250-kW Kenetech power processing unit and an identical 2-MWh battery bank (SEC C100-27 batteries). The systems have identical factory-built equipment enclosures to house the power processing units and associated controls and switchgear, and they use identical sub-array assemblies of ASE 300DG modules from Applied Power Corporation for the photovoltaic arrays. The procurement office is the Naval Air Warfare Center Weapons Division at China Lake.

Fort Carson Water Pumping, Colorado

The Fort Carson photovoltaic project was approved as an ECIP project in 1992 to install some 39 different water pumping systems to replace aging windmills on the military reservation. In early 1995, Fort Carson personnel attended a photovoltaic water pumping workshop, hosted by members of the Photovoltaic Services Network (PSN). Working with the PSN, Fort Carson decided to turn its project into a demonstration of currently available photovoltaic water pumping technologies (22). Through summer-1995, eight different systems, using both ac and dc submersible pumps, were installed. The systems include: SolarJack (dc centrifugal), Golden Photon (ac centrifugal), A.Y. McDonald (dc centrifugal), Applied Power Corp. (ac centrifugal), EPV (ac centrifugal), Photocomm (ac centrifugal), and Robinson (dc centrifugal). Fort Carson has since selected the Photocomm system for the other sites. About 30 systems have been installed to date with the remainder to be installed by spring of 1997. This project is being implemented by Fort Carson's Directorate of Environmental Compliance and Management.

Pohakuloa Training Area Ranges, Hawaii

A solicitation for multiple photovoltaic systems at the Army's Pohakuloa Training Area is in preparation and is scheduled for release by the end of 1996. The training area is a large range located between Mauna Kea and Mauna Loa in the interior of Hawaii. Approximately 70% of the range is not served by the utility grid. At this time, there are no plans to extend the grid into these remote areas and, as a result, the Army must provide its own power for training activities. This solicitation will provide photovoltaic power for control towers at 12 target ranges, it will convert 56 diesel powered pop-up targets to photovoltaic power, it will hybridize two diesel powered large track targets, and it will power runway lights for Bradshaw airfield. The control towers and pop-up targets systems will be powered by stand-alone photovoltaic systems. Each control tower will have about 400 W of photovoltaics and 6 kWh of battery to power warning beacons, interior lights, a public address system, portable computers, and radio communications. Each pop-up target will be fitted with a single 10-Watt photovoltaic module and 100-Ah 12-Volt battery. The track target hybrids will add about 5 kW of photovoltaics, 600 kWh of battery, and 30 kVA of power processing to the existing 60-kW generators. The runway light requirements have not yet been fully defined. The array will be between 1.5 - 2 kW and the battery will be about 600 kWh. The system will be backed up by the utility grid. The procuring agency is the Pacific Ocean Division of the US Army Corp of Engineers. The request for proposals is scheduled for release in December 1996.

Yuma Proving Ground Grid-Tied System, Arizona

In early 1995, Utility Power Group won two prime contracts for a photovoltaic power station and a complementary battery storage/load leveling project for a total amount of $5.5M. The photovoltaic power station was funded at $3.9M by ECIP, and the battery storage/load leveling project was funded at $1.6M by SERDP. The two systems were integrated into a photovoltaic/battery-enhanced peaking station. The system includes 441 kW of Siemens M-55 modules, four 225-kW Kenetech power processing units, and 5.6 MWh of C&D C125-19 batteries. Under normal operating conditions during the summer peak demand season, the system will be capable of delivering up to 825 kW to the grid to help Yuma Proving Ground with high demand rates. The system will also be capable of operating in a stand-alone mode if an extended power outage is experienced. On a limited basis, the stand-alone system would continue to operate the Proving Ground's nearby water treatment plant and other emergency communications loads (see reference 21 for a detailed description of

this system). Construction is 95% complete. The system is expected to be fully operational in January 1997.

Smart Munitions Complex, Yuma Proving Ground, Arizona

Yuma Proving Ground is currently preparing specifications for a photovoltaic/diesel hybrid system using 225 kW of ASE 300DG modules and 3.5 MWh of Absolyte IIP 100A75 batteries that were purchased under the SERDP program. The hybrid system is the first element in the development of a new range area at the Proving Ground. It will initially power a new smart munitions test complex and will be expanded to serve as a micro-utility for multiple facilities in this developing range area. Yuma is contributing about $0.5M from its project funding accounts to create a functional system from the $1.5M worth of modules and batteries in its possession. This will be the first major DoD installation to use the valve-regulated battery technology. The system is expected to be completed in the summer of 1997.

Mobile Power Center, California

A mobile power center has been developed for the 1st Marine Expeditionary Force at Camp Pendleton, California. It is designed to interface with either the commercial utility or generators and will have 3.2 kW of Solarex MSX-95ML modules, a 1-kW World Power Whisper 1000 wind turbine, a 6-kW Abacus inverter, a 3-kW IBE battery charger, and a 58-kWh C&D C125-21 battery. The mobile power center is a partially SERDP-funded research and development project designed to incorporate hybrid capabilities in a mobile package that is compatible with standard military equipment and suitably robust for military operations. The unit addresses the need to simplify the logistics of power requirements for tactical military exercises as well as enhance the reliability of the missions. The system was designed and constructed by Naval Research and Development in San Diego and is currently under test at Camp Pendleton.

Ascension Island Runway Lighting, Mid-Atlantic Ocean

Integrated Power Corporation was awarded $1M to design and install a grid-interactive photovoltaic system for runway lighting at Ascension Island. The system includes 86 kW of ASE 300DG modules and a 120-kW Kenetech power processing unit. The system will supplement the island diesel generator power plant. It can also be upgraded with batteries to operate the runway lights

independent of the island grid. The system has been designed, and hardware is being shipped to the island. Construction is scheduled to begin in February 1997, and the system is expected to be operational by the end of April 1997.

Solar Regenerative Fuel Cell Cooperative Project, California

This is a cooperatively funded demonstration project with the Jet Propulsion Laboratory at Edwards Air Force Base. The Navy Energy Program Office based at China Lake procured and installed two different 25-kW Cadmium Telluride thin-film photovoltaic arrays - one manufactured by Solar Cells Inc. and the other by Golden Photon Inc. The system, which has been operational since August 1996, also includes two 25-kW Abacus maximum power trackers, an electrolyzer system, and a fuel cell. The direct current produced by the photovoltaic arrays powers an electrolyzer system that separates water into hydrogen and oxygen. The hydrogen and oxygen are recombined in the fuel cell to produce heat, electricity, and water. NASA regards a regenerative photovoltaic fuel cell power plant as a possible option for advanced human space exploration. The DoD will gain operational experience with an emerging, potentially lower-cost photovoltaic technology.

Santa Cruz Island, California

This project was the only photovoltaic project approved in the FY 1996 ECIP budget cycle. The project was procured through Southern California Edison's off-grid tariff program and includes two systems: a photovoltaic/diesel hybrid for a mountain-top communications station, and a photovoltaic water pumping system. The hybrid system will include 138 kW of photovoltaic modules, 2700 kWh of batteries, and a 150-kW power processing unit. The water pumping system will include 11 kW of photovoltaic modules. Edison has solicited and evaluated bids from photovoltaic system suppliers for the design and installation of the two systems. The system suppliers will be announced in November 1996. The project is scheduled for completion by June 1997.

SUMMARY

The first organized effort to integrate photovoltaics into military practices dates back to the late 70s when all branches of the DoD participated in the Department of Energy's Federal Photovoltaic Utilization Program. This led to the creation of the DoD's Tri-Service Photovoltaic Review Committee chartered in

1985 to foster the use of photovoltaics throughout the DoD. The Photovoltaic Review Committee has identified nearly a 4 GW potential for photovoltaics in stand-alone, photovoltaic/generator hybrids, and utility-interactive applications. The Photovoltaic Review Committee, with technical support from the Department of Energy through Sandia National Laboratories, works to integrate these applications into standard military practices so that they are used where cost-effective. The Photovoltaic Review Committee initially focused on the small remote applications area (stand-alone and hybrid systems less than 25 kW). By 1992, DoD had installed 2,000 small remote systems with 2 MW of photovoltaics.

In 1992, funding from SERDP and ECIP allowed the Photovoltaic Review Committee to shift emphasis to larger hybrid systems in the intermediate/large remote and isolated grid applications areas. Under Sandia direction, SERDP funds were used to develop, test, and demonstrate the power processing hardware required for larger hybrids and the ECIP funds were used to field 12 hybrid systems at installations covering a wide range of environmental and operating conditions. Today, intermediate sized hybrids are considered ready for implementation, with the larger hybrids only 2-3 years behind. A total of 124 systems with 2.1 MW of photovoltaics were procured with SERDP and ECIP funding. In addition to the 12 hybrids, these systems include 108 stand-alone systems, 3 utility-interactive systems, and a regenerative fuel cell application using the new Cadmium/Telluride thin-film photovoltaic module technology. The 120 systems funded by ECIP are cost-effective applications.

The Photovoltaic Review Committee will continue its work with larger hybrid systems and will move on to the utility-interactive applications as they become cost-effective. Sandia will continue to support the Photovoltaic Review Committee in both project and technology development. The level of activity, however, will vary with the available resources.

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